MDDC - 766

UNITED STATES ATOMIC ENERGY COMMISSION

COUNTING RATE METER BASED ON A DESIGN BY M.I.T.

by

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Date Declassified: December 31, 1946

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Technical Information Branch, Oak Ridge, Tennessee
AEC, Oak Ridge, Tenn., 4-22-49--850-A3759

Printed in U.S.A.
PRICE 10 CENTS

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INTRODUCTION AND PURPOSE OF THE INSTRUMENT

The Counting Rate Meter herein described was built largely from designs contained in the Massachusetts Institute of Technology report entitled "Improvements in the Counting Rate Meter".

The purpose in building this instrument was to produce a counting rate meter to operate in conjunction with a recording galvanometer (in this case a 5 milliampere Esterline-Angus recorder) to indicate and record counting rates of from 50 to 20,000 counts per minute accurate to within 5% for randomly distributed pulses. The range of from 50 to 20,000 counts per minute was accomplished in seven separate ranges. This counting rate meter will be useful in studying radiations from sources having half-lives greater than 1 1/4 minutes for ranges 1, 2, and 3 and greater than 50 seconds for ranges 4, 5, and 6 and greater than 25 seconds for range 7. (See Appendix for mathematical treatment of this.)

To facilitate easy calibration check of the instrument a Pulse Generator producing pulses at exact multiple and sub-multiple frequencies of 60 cycles per second was included with the Counting Rate Meter.

Although the instrument is designed to count beta and gamma radiations operating from a Geiger-Mueller tube it could be used with a standard chamber and pre-amplifier to count alpha particles.

Calibration curves of the "Counts per Minute" meter are included in the Appendix at the end of this report. The curves are plotted to show the calibration for both random and periodic pulses. The calibration with random pulses was accomplished by measuring the counting rate of a beta-gamma source using a G-M tube and the Counting Rate Meter and checking the "Counts per Minute" meter reading against a scaler operating from the "Scaler" pin jack on the Counting Rate Meter front panel. The calibration with periodic pulses was done using the Pulse Generator. Although the calibration has shown a tendency to drift from day to day this condition may improve when the meter is put into continuous operation.

OPERATING AND CALIBRATING INSTRUCTIONS

For easy installation and subsequent operation of the Counting Rate Meter the following procedure is recommended:

1) Plug in AC power cord and turn "Line" switch on. (Note that the instrument should operate from a 115 volt regulated line.)

2) Now allow one hour for the instrument to warm up. Inaccuracies will result from attempts to use the instrument before it has reached operating temperature. If the instrument must be used without warming up, do not attempt to make adjustments in the calibration until ambient temperature has been reached.

3) After warm up press "Reset" switch and hold depressed. If "Counts per Minute" meter does not read zero, adjust it to zero with the "Zero Set" knob.

4) If it is desired to use the instrument without recalibration, skip over to instructions No. 5. If it is desired to completely recalibrate the instrument, proceed as follows:

a) Place a 16 1/2 volt battery across the "16 1/2 Volt Check" pin jacks and adjust the "Full Scale Set" knob so that the "Counts per Minute" meter reads full-scale.

b) Place "cpm" selector switch on range No. 1 and Pulse Generator "Frequency" selector switch on range No. 1, turn Pulse Generator "Plate" switch on and throw "Calibrate-Operate" switch to "Calibrate". Wait six minutes. If the instrument is properly calibrated the meter will read 225 counts per minute, (the second red mark on the scale). If at the end of the six minute period the meter does not read 225 counts per minute the 6AC7 Integrator tube screen voltage needs to be adjusted. Along the right hand edge of the chassis there are seven potentiometers for adjusting the screen potential of the 6AC7 Integrator tube on each of the seven counting rate ranges. The potentiometers are arranged in order, potentiometer No. 1 being at the rear of the chassis and potentiometer No. 7 being at the front of the chassis. The numbers of the potentiometers correspond with the numbers of the ranges on the "Counts per Minute" meter and the Pulse Generator "Frequency" selector switch.

To adjust the "Counts per Minute" meter to read 225 counts per minute on range No. 1, break the seal on No. 1 potentiometer and turn it slightly. Turning it clockwise will decrease the meter reading and turning it counter clockwise will increase the meter reading. After each adjustment it will take six minutes for the meter to reach equilibrium so that it is necessary to make only small changes in the potentiometer setting and use a good deal of patience in the process. When six minutes after the last adjustment has been made, the meter reads 225 counts per minute (the second red mark on the scale), the meter will be properly calibrated on range No. 1. Now proceed similarly with the other six ranges.

Below is a table giving the range numbers, full-scale frequencies, calibration frequencies, and time required to reach a reading.

Range No.	Full-scale frequency (cpm)	Calibration frequency (cpm)	Time in minutes to reach a reading
1	250	225	6
2	500	450	6
3	1000	900	6
4	2000	1800	4
5	5000	3600	4
6	10,000	7200	4
7	20,000	14,400	2

c) For greatest accuracy it is well to check the frequencies of the Pulse Generator. This may be done with an oscilloscope by synchronizing the oscilloscope with the 60 cycle line frequency and obtaining an exact number of stationary sine wave cycles on the oscilloscope screen and then placing the scope probe in the pin jack on the rear of the Pulse Generator chassis marked "Scope" and noting the number of stationary negative pulses which appear. The correct numbers of sine wave cycles and pulses are given in the following table:

Range No.	Calibration frequency (cpm)	Number of negative pulses	Number of sine wave cycles
1	225	1	16
2	450	1	8
3	900	1	4
4	1800	1	2
5	3600	1	1
6	7200	2	1
7	14,400	4	1

5) If it is desired to use the instrument with an Esterline-Angus recorder (5 milliampere movement) connect the recorder to the Counting Rate Meter with the phone plug and cable provided observing the polarity markings on the cable.

It may be necessary to adjust the matching of the recorder to the Counting Rate Meter. This is done with the potentiometer located in the right hand front corner of the chassis. This potentiometer may be identified easily as it has a 3 inch long extension shaft making it easy to reach from within. Turn the potentiometer until it is set in such a position that the "Counts per Minute" meter reads the same whether the phone plug is in or out. It is to be noted that the Esterline-Angus and the "Counts per Minute" meter will read the same regardless of the matching adjustment given above. However, if the matching is not carried out properly both meters will read incorrectly.

6) The instrument is now ready to be put into use. Connect the G-M tube with the cable provided. (The shield on the cable connects to the wall of the G-M tube and the wire of the cable connects to the wire of the G-M tube.) Turn on and adjust the "High Voltage" to the desired value. Select the proper "cpm" range, throw the "Operate-Calibrate" switch to "Operate" and after the proper time has elapsed read the counting rate directly from either the recorder or the "Counts per Minute" meter.

DESCRIPTION OF THE ELECTRICAL CIRCUIT

The circuit may be divided into seven units for description. These are:

1) Regulated Plate Voltage Power Supply.
2) Regulated High Voltage Power Supply.
3) Neher-Pickering Quenching Circuit.
4) Amplifier and Pulse Equalizer.
5) Integrating Circuit.
6) Vacuum Tube Voltmeter Circuit.
7) Calibrating Pulse Generator.

1. Regulated Plate Voltage Power Supply

The plate voltage power supply is a conventional full wave rectifier circuit using a 5Y3 rectifier tube, a pi section filter, dropping resistor, another condenser and two VR 105 tubes to provide direct current regulated at 105 and 210 volts.

2. Regulated High Voltage Power Supply

The regulated high voltage supply is essentially the usual Clinton Laboratories circuit as shown on drawing. There are a few noticeable differences in the two circuits. First an RCA No. 33390 transformer was used which provides all necessary windings except those for the filaments of the 6J7 and the 809. Using this transformer, it was found desirable to use four 200,000 ohm resistors rather than five in series with the meter and its shunt, and to use a 300 ohm shunt across the meter rather than a 100 ohm shunt as shown. Also a 6.3 volt winding with a 100 ohm dropping resistor was used to heat the 1N5 filament instead of a 2.5 volt winding with a 25 ohm resistor.

3. Neher-Pickering Quenching Circuit

The Neher-Pickering Quenching circuit provides rapid quenching of the G-M tube and at the same time makes it possible to ground the wall of the G-M tube.

Its operation may be described as follows: Prior to the arrival of a beta particle within the G-M tube, its central wire which is connected to the 6J7 grid is kept at a high potential due to the flow of plate current from the high voltage supply through the 6J7 and the 6 megohm resistor connected between the 6J7 cathode and ground. As soon as the G-M tube starts to discharge, current flows through the grid resistor thereby making the grid negative with respect to the cathode so as to cut the tube off. With the tube cut off, the voltage on the central wire of the G-M tube is lowered and hence the discharge of the G-M tube stops. The grid then comes back to cathode potential and the 6J7 starts to conduct, again raising the voltage on the central wire of the G-M tube. The circuit is now ready for the arrival of the next beta particle.

4. Amplifier and Pulse Equalizer

Quoting MIT report "Improvements in the Counting Rate Meter". "The Amplifier stage provided between the Neher-Pickering circuit and the Pulse Equalizer is used in order to insure that a minimum pulse size from the counter tube will be sufficient to actuate the Pulse Equalizer and to sharpen the pulses down to the resolving time of the Equalizer (10^{-5} sec) so that in no case will a single pulse allow the Equalizer to give more than one pulse. The Equalizer is a conventional multivibrator, biased below cut off. To adjust the multivibrator, the cathode potentiometer is turned until oscillation occurs, and is then turned back just far enough so that it does not have any tendency to oscillate. (It may oscillate as the set is turned on or off.)"

Coupling of the signal from the Neher-Pickering circuit to the Amplifier tube is accomplished by means of a special condenser constructed to withstand the full G-M tube voltage. This condenser was made by us on the basis of recommendations in the MIT report in which they stated that commercial mica condensers leak sufficiently to cause spurious counts. The special condenser was made by clamping a piece of mica of the proper thickness to give the desired capacity, between two brass plates about 1 centimeter square. The mica was made larger than the metal plates so as to provide a long leakage path. The whole thing was then clamped between polystyrene blocks and bolted to the chassis.

5. Integrating Circuit

Quoting the MIT report: "The Integrating circuit consists of a CR tank circuit which is fed through a vacuum tube by the constant sized pulses produced by the multivibrator. The voltage on the condenser is read by a vacuum tube voltmeter, this reading being a measure of the average counting rate." (A brief mathematical treatment of this circuit will be found in the appendix at the end of this report.)

"The sensitivity of the tank circuit tube is varied in two ways: first, by varying its screen potential; second, by varying the R of the tank circuit. These two controls are gauged, so that when changing counting rate range, the time constant is appropriately changed, since the long time constant of 1

minute which is useful at low counting rates, is unnecessary at high counting rates." The counting rates for full-scale deflection of the meter, with corresponding time constants of the CR circuit are given below.

Range	Full-scale counting rate (cpm)	C.R. (sec)	Calibrating frequency (cpm)
1	250	60	225
2	500	60	450
3	1000	60	900
4	2000	40	1800
5	5000	40	3600
6	10,000	40	7200
7	20,000	20	14,400

The 2 μf tank circuit condenser was made by paralleling two 1 μf - 200 volt polystyrene filled condensers manufactured by the Western Electric Co. The polystyrene filled condensers were used to reduce dielectric hysteresis to a negligible quantity.

Dielectric hysteresis is the phenomena in which a condenser which has apparently been discharged by short circuiting, recharges itself due to the storage of charge within the dielectric rather than merely on the condenser plates. Both oil-filled and paper insulated condensers show this tendency and if either of these types were used here, the Counting Rate Meter would read incorrectly due to the charge held over from previous counting in the dielectric of the condenser. The polystyrene condenser seems to be entirely free from this difficultly and may be completely discharged in about 2 seconds by pressing the "Reset" switch.

6. Vacuum Tube Voltmeter Circuit

Quoting the MIT report: "The vacuum tube voltmeter is highly degenerative, with a consequent high degree of linearity. It gives a full-scale reading of 5 milliamperes in order to allow the use of a 5 ma pen and ink recorder (an Esterline Angus). Both the voltmeter and the tank circuit are arranged so as to cancel out all first order effects due to changes in voltage across the VR tubes."

An internal resistance of 1000 ohms is provided in the voltmeter output; this resistance being replaced by a potentiometer and the recorder resistance when the recorder is connected. This makes it easy to match the recorder to the Counting Rate Meter so that it will read the same with or without the recorder connected.

7. Calibrating Pulse Generator

The Pulse Generator furnished with the instrument at the present writing is essentially a multivibrator connected to lock in at multiple and sub-multiple frequencies of 60 cycles. Up to the present writing considerable difficulty has been experienced in attempting to make the Pulse Generator lock in on certain ranges. It is the intention of the writer, if necessary to rebuild the Pulse Generator or make whatever changes are necessary to cause it to operate properly. After this has been done a complete description of the Pulse Generator will be furnished together with a drawing of the final unit.

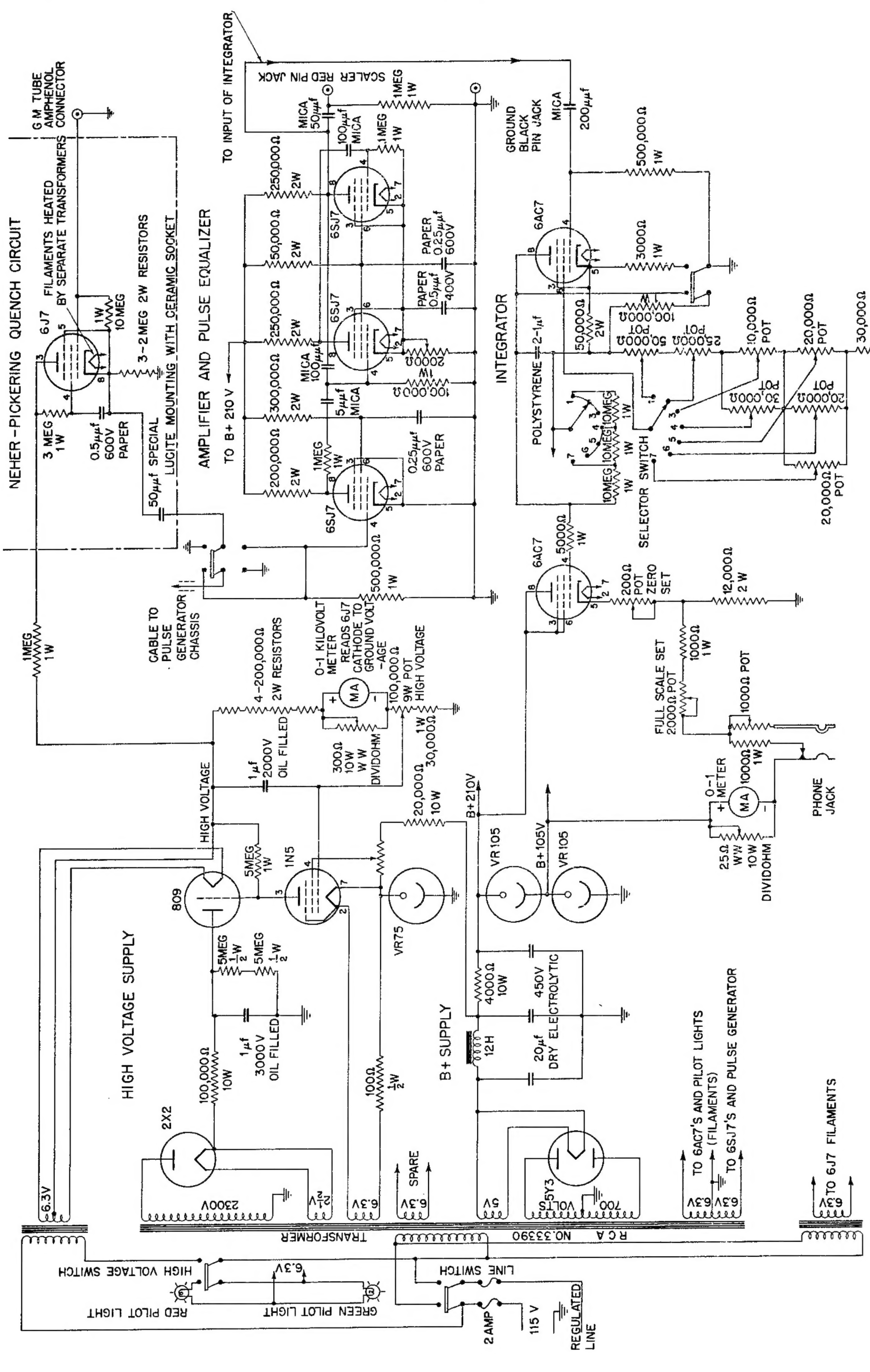

Figure 1. Circuit diagram of counting rate meter.

SUGGESTED IMPROVEMENTS IN ANY FUTURE UNITS

1) Provide a more stable Pulse Generator.

2) Use wire wound resistors in the Vacuum Tube Voltmeter circuit.

3) A somewhat better arrangement of the circuit elements on the top of the chassis would probably be possible.

MAINTENANCE SUGGESTIONS

1) Check calibration of Counting Rate Meter and Pulse Generator. See Operating and Calibrating instructions.

2) If necessary to replace either 6AC7 tube, use only tubes which test about 20% better than rated mutual conductance values on a Hickok tube tester.

APPENDIX

MATHEMATICAL ANALYSIS OF THE INTEGRATING CIRCUIT

The following is a synopsis of an article by Schiff and Evans, R.S.I. 7. 456. (1936). All credit is acknowledged to Schiff and Evans.

A. Long Life Sources

1) Expected Charge in the Steady State

Assuming a radioactive source of constant strength producing randomly distributed pulses we denote the average number of pulses received per unit time by the constant x.

Similarly q = Quantity of charge placed on the condenser with each pulse - A constant.

C = Capacity of Condenser - A Constant.

R = Resistance across condenser - A constant.

t = Time - A variable.

Then the expected charge Q on the condenser at the time of any reading t_o after steady state conditions have been reached is:

$$Q = \int_{-\infty}^{t_o} qxe^{-(t_o - t)/RC}\,dt = qxRC$$

which holds for random or periodic pulses.

2) Statistical Fluctuations in a Single Observation

To determine the standard deviation of a single reading we use the relation that if N randomly distributed events are expected in unit time the actual number of events which are likely to occur will be $N \pm \sqrt{N}$

This holds for events distributed in time according to Poisson's Law such as all radioactive disintegrations.

Thus the standard deviation of the charge placed on the condenser in a time interval dt is $q(xdt)^{1/2}$

Similarly the contribution of this deviation to the deviation of the condenser charge observed at a time t_0 is

$$q(xdt)^{1/2}\, e^{-(t_0 - t)/RC}$$

so that summing the squares of these contributions we have:

$$(\text{Standard deviation})^2 = \int_{-\infty}^{t_0} q^2 x\, e^{-2(t_0 - t)/RC}\, dt = q^2 x \frac{RC}{2}$$

The expected fractional standard deviation of single reading is then:

$$\Delta = \frac{\text{Standard deviation}}{Q} = \frac{\sqrt{q^2 x\, RC/2}}{qx\ RC}$$

$$\begin{array}{l}\text{Fractional}\\ \text{Standard}\\ \text{Deviation}\end{array} = \frac{1}{\sqrt{2x\ RC}}$$

3) Probable percentage error of a single reading

$$\text{Probable \% error} = \frac{0.6745}{\sqrt{2x\ RC}} \times 100\%$$

Thus we see that the theoretical accuracy of the instrument depends on the strength of the source and the time constant of the tank circuit.

Below is a table giving the probable errors for full scale and 1/10 scale readings on each of the seven ranges of the Counting Rate Meter.

Range	% error at full-scale	% error at 1/10 scale
1	3.0%	9.6%
2	2.1%	6.7%
3	1.5%	4.7%
4	1.3%	4.1%
5	0.8%	2.6%
6	0.6%	1.8%
7	0.4%	1.3%

These figures are of course just the theoretical probable errors assuming a perfect instrument.

B. Short Life Sources

4) Expected Charge at Any Time for a Decaying Source

Assuming a radioactive source containing N_0 atoms on the average at time $t = 0$ with a decay constant λ per second, the disintegrations are distributed according to Poisson's Law with an average value at a time t of $\lambda N_0\, e^{-\lambda t}$

Also assuming a background counting rate of β counts per second we have for the charge at any time T (where time is measured from the moment of introducing the decaying source).

$$Q = q\int_{-\infty}^{0}\beta e^{-(T-t)/RC}\,dt + q\int_{0}^{T}(\beta + \lambda N_0 e^{-\lambda t})\,e^{-(T-t)/RC}\,dt$$

$$= qRC\left\{\beta + \frac{\lambda N_0}{1-\lambda RC}\left(e^{-\lambda T} - e^{-T/RC}\right)\right\} \text{for } \lambda \neq \frac{1}{RC}$$

$$= qRC\left\{\beta + \lambda^2 N_0 T\, e^{-\lambda T}\right\} \text{ for } \lambda = \frac{1}{RC}$$

5) Time at which Maximum Output Current Flows

Differentiating (4) we obtain:

$$T^*_{max} = \frac{2RC \ln \lambda RC}{\lambda RC - 1}$$

Thus the recorder will show a curve rising to a peak and then decaying to zero with the peak T_{max} seconds after introducing the source.

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*Note: Schiff and Evans give this as: $T_{max} = \dfrac{RC \ln \lambda RC}{\lambda RC - 1}$

END OF DOCUMENT